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Social and Behavioral Sciences

Procedia - Social and Behavioral Sciences 104 (2013) 1198 – 1207

2nd Conference of Transportation Research Group of India (2nd CTRG)

The Role of Road Transport in Scheduled Air Cargo Networks

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Abstract

For the conduction of quantitative research on airfreight related topics, this contribution summarizes recent efforts to handle intra-continental airfreight surface transport operations in the context of an origin and destination routing model. The distinguishing features of this approach are the O-D scope in combination with the explicit use of period timetables of a sample week, not just weekly averages. Two forms of appearance on intra-continental short- and medium-haul routes – with a complementary and a substitutive function regarding cargo flights – are distinguished: Access and egress of consolidation / deconsolidation airports for delivery and pick-up, and airline trucking (“road feeder services”/ RFS, “truck-flights”) of airway billed consignments between two airports. The methodology comprises an empirical characterization of the supply side of both the air cargo consolidation and the airline trucking markets, the subsequent modeling of surface transport links within a scheduled network in terms of the surface links’ network topology, attainable journey times and hours-of service regulation for truck driving, and the simulation of RFS load pattern in the context of a global air cargo model.

Keywords: Air Cargo; Transport Modeling; Road Transport; Trucking; Road Feeder

1. Introduction

1.1. Relevance of air cargo modeling

Air freight services are vital to supply chains of a globalized economy. Although this mode of transportation has just a relatively small share in tonnages compared to ocean freight, not less than one third of the values in international trade are conveyed by air. Scheduled air cargo services account for 90 to 93 per cent of the overall tonnage, excluding the remaining 7 to 10 per cent of ad-hoc or specialty air transportation by chartered freighters or flying services using small, general-purpose equipment. Scheduled air freight and passenger networks have developed - under comparable competitive constraints - in congruence with as well as apart from each other. To

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doi:10.1016/j.sbspro.2013.11.216

model the complexity of air cargo - in terms of distinct flow asymmetries, differentiated commodity groups, its forms of occurrence (belly cargo, freighter, trucking), the multi-leg transport chains with corresponding sorting and customs clearance stages, manifold routing options, aircraft specifications with limitations e.g. by weight, volumetric capacities, cargo door sizes and the tariff system - appears a demanding task.

An independent rationale for public decision making on air cargo transport would be needed. However, in comparison to passenger air transport, a disproportionate coverage and an early stage of model standardization can be noticed. Given the paucity of non-proprietary, transparent, disaggregate data on air cargo networks flows, the situation gave rise to the systematic, stepwise modeling of origin to destination air cargo routing aspects.

1.2. Road transport in air cargo networks

A rising part of air trade is also transported by road - during airport access and egress (so-called "forwarder trucking" or "direct delivery"), that is, complementary, as well as substitutive to freighter flights (so-called "airline trucking", "road feeder service"/RFS or "truck flights"), and recognized by a published flight number. Figure 1 depicts these two cases in connection with three typical versions of process chains of intermediaries, typically orchestrated by air freight forwarders ("agents"), or integrators.

Particularly secondary airports or fragmented markets, where the weekly amount of consignments may not reach the quantity threshold justifying costs of freighter operations, depend on stable, frequent trucking connections to at least one continental air cargo hub. Trucking does not just connect smaller markets with adequate feeder capacities, but mainly addresses the need for downsized, cost-effective, yet frequent services. This was noticeable in the course of the industry crisis, by modal shifts to trucking and the competing ocean lines for less time-critical cargo.

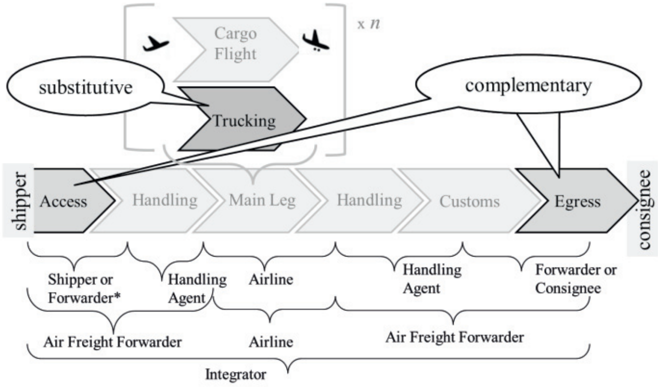

Fig. 1. Complementary and substitutive role of road transport of air cargo (Source: Own representation)

Surface transports of air freight are a key playing field in the continent's inter-hub, inter-airline, and inter-modal competition. Absorbed freight at the periphery fills the freighter (over-)capacities of the hubs. Consequently, the actual catchment areas of major cargo airports have large diameters, with the consolidation and deconsolidation links often reaching vast parts of the continent. Thus, the overlap of air cargo catchments is rather rule than exception. According to the latest World Air Cargo Forecast, the truck-flight frequencies in Europe have risen by factor five in just ten years, serving three times more city pairs than 2002 (Boeing, 2012).

The representation of general or carrier-specific surface transport networks and their respective quantity structures allow for a better understanding of their role within air cargo transport chains and the interaction with the road network conditions. A completely covered door-to-door transport chain shall explain the total shipping times, the sensitivity of air cargo routing to surface networks' levels of service (geography, speed, reliability) versus transport fares. A possible dominance of specific commodity groups or market segments is also of interest.

On the other hand, the raised complexity of routing for an adequate reconstruction of surface transport of air cargo in the context of origin-destination demand assignment poses several challenges to the modeler. There are still methodological gaps to overcome when representing the forwarders' perspective. Despite of the described relevance, there is a lack of publicly available statistical data differentiating between freighter and truck operations. This article seeks to contribute empirical findings as well as modelling approaches and results to fill such data gaps.

1.3. Previous work

The important role of air cargo road transport was anticipated early, for instance, by Arendal (1992), exemplary for Europe's emerging domestic market. The textbook of Morell (2011) gives the latest comprehensive description of the technological and economic background of air freight in general. The theoretical basis of transport modeling is laid, for example, by the textbook of Ortùzar and Willumsen (2011). Brinkmann (2009) summarizes the legal aspects of road feeders. Air-cargo related scholarly literature exhibits three dominant views: air cargo facilities at airports, cargo fleet planning, and institutional aspects. Related air cargo models were proposed and implemented for the prediction of O-D market shares depending on carriers' levels of service (Diamond, 2002), air cargo schedule planning problems, models, and algorithms (Lohatepanont, 2012), the fleet assignment & cargo routing (Li, Huang et al., 2006), a description of the air freight transport geography (e.g. Bowen, 2009), the airport choice of freighter operators (Kupfer et al., 2011) as well as the optimization of truck handling operations at an air cargo terminal (Franz et al., 2012). Noticeably, the air cargo demand assignment problems covering the entire transport chain are rarely stressed in the available literature. Furthermore, airline network problems are often studied excluding the demand side, thus avoiding the demand assignment problem of flow matrices to time-space networks under consideration. A systematic route typology, as well as a methodology for subsequent choice set formation was developed in Heinitz and Meincke, 2011. In continuation of this, the framework of Heinitz and Meincke (2013) tackles the O-D demand assignment problem.

1.4. Paper objectives, methods and structure

This article seeks to contribute an as-is analysis of air cargo road transport in its two forms of appearance. Inferred from these findings, constituents of a model representation of the entire transport chain will be developed and tested. The primary research methods are descriptive statistics, network visualization techniques, and network routing simulation runs.

The paper is organized as follows: Section 2 characterizes air access and egress links, deriving assumptions for modeling the vehicles and network structure (2.1), and the resulting level of service (2.2). An empirical analysis of road feeder services is presented in Section 3, dealing with the RFS network structure (3.1), the results of the timetable analysis (3.2), and the road network assignment (3.3). The following Section 4 introduces the modeling framework the modeled surface transport links will be built in. The origin and destination routing (4.1) and the demand assignment step (4.2) will be stressed. A summary, a discussion of results as well as an outlook to future research will be provided by the concluding Section 5.

2. Airport access and egress links

2.1. Vehicles and network structures

The expeditors' forwarding for airport access and egress has to be distinguished from RFS, that is, airway billed trucking between airports on behalf of the air carrier. Table 1a) depicts the approximate proportions of vehicles types, exemplary given in the textbook of Mensen (2013). Assuming a range of consignment weights, the corresponding percentages of weight, percentages of passenger cars and light vans become negligible. Therefore, we assume the deployment of truck/trailer road trains for all containerized or palletized shipments.

The relative number of access and egress (or export and import) deliveries is small from the airport perspective. Road feeders make up more than three quarters of an airport's the road terminal utilization. As shown in Table 1b, there is a considerable share of ad-hoc RFS movements, replacing or complementing freighter flights.

Table 1 a/b. Air freight - down-break by access vehicle type (a, cf. Mensen, 2013) and movements by service (b, Source: Franz et al., 2012)

Vehicle type	% shipments	% weight
Passenger car	40	1
Light van	20	2..5
Truck	25	23..25
Truck/trailer combination	15	69..73

Service	% truck movements
RFS scheduled	58.5
RFS ad hoc	21.4
Export by forwarder	7.5
Import by forwarder	12.6

For a cost-efficient handling and onward transport, expeditors centralize the delivered and collected air freight at their warehouse locations. The airports reached from these bundling locations are interchangeable in principle. For Germany, Horn (2013) substantiated the airport choice from such warehouse locations, depending on the road distance to overcome, schedule and capacities of the considered departure airports.

An exemplary origin analysis of export flow data for 26 Brazilian airports is displayed in Figures 2/3. The range of obtained concentration ratio (CR_x) coefficients suggests that 2 to 3 linked airports per forwarder location and 3 to 4 (out of 45) forwarder locations per airport describe the mapping with sufficient precision. Adopting this finding for later modeling implies that the choice set sizes may be kept within manageable bounds.

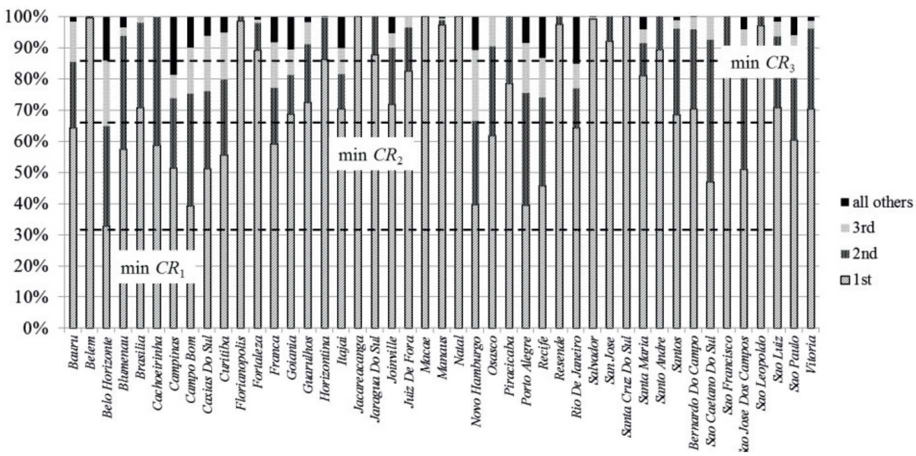

Fig. 2 . Airport market shares by forwarder location, CASS export freight tons for Brazil, July 2007 (Source: Own computation)

For modeling purposes, the representation of supply chains has to be simplified into an algorithmically manageable system of zones, also referred as "traffic cells". The road access and egress networks consists of airport connector arcs, originating at virtual centroids – or – in case of a more detailed approach – at the forwarder locations. Note that it remains an open issue whether agents can bypass intermediate warehouses or not.

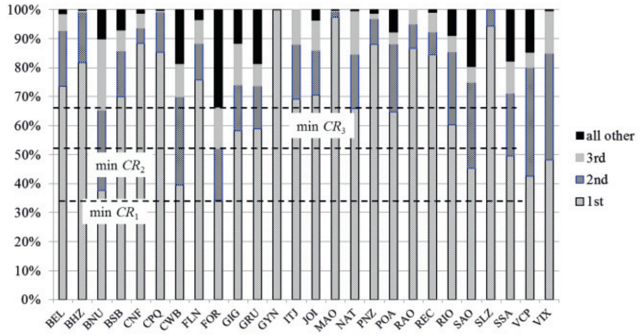

Fig. 3. Forwarder location market shares by airport, CASS export freight tons for Brazil, July 2007 (Source: Own computation)

Level of Service

The level of service of all access and egress links – that is, frequencies, transport times and cost – is meaningful for the route search framework, to be introduced in Section 4. With the help of a road transport model, the time-minimizing route between centroid node and airport is identified. If there is no surface network model available or uncertainty of the exact geographic locations, the circa transport duration can be obtained by the quotient of the minimum of origin and destination cells' approximate and the road distances centroid-airport, queried from online route planners. Trucks are subject to the hours of service (HoS) regulations. The journey times thus are extended by the respective rest times (Table 2). For locations farther away from the airport hub than the distance of the working day's mileage, the hub's accessibility makes it much less attractive. The resulting journey times for 846 airport-connecting truck routes, observing local HoS rules, are depicted in Figure 4a.

Table 2. Hours-of-service rules for in comparison (Source: Own representation, cf. Goel and Vidal, 2012)

Area	Legal foundation	Required break [h]/ after non-stop driving time[h]	Daily rest min. duration [h]/ after driving time of [h]
E.U. and A.E.T.R. countries*	EC 561/2006	.75/4.5	11/9
U.S.A.	FMCSA 2011	-	10/11
Canada	TC SOR/ 05-313	-	8/13**
Australia	NHVAS, 2008	.25/5.5 and 2x.25/8	10/14

* includes Russia ** may be transferred to the following day, as long as weekly limit met

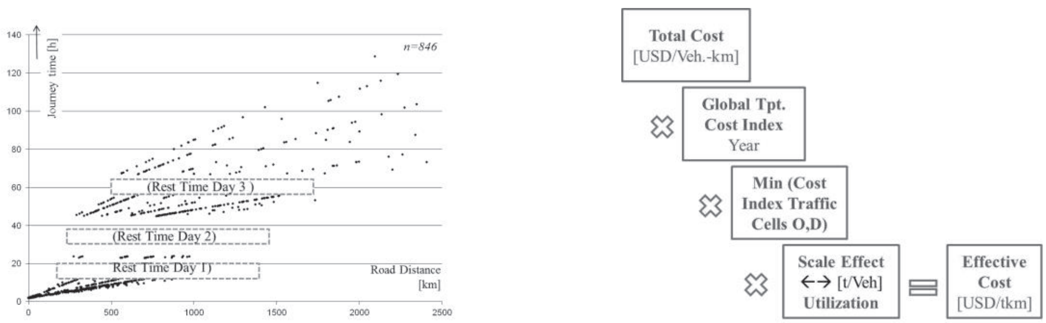

Fig. 4a/b Modeled truck journey times for connector links (a), Outline of road transport cost model (b) (Source: Own representation)

The effective costs in US-$ per freight ton-kilometer (FTK), differentiated by mission and vehicle load, will be computed according to Figure 4b. Based on this, the access and egress unit costs at varying demand levels are provided for the level of service evaluation for the examined origin-destination (O-D)/city pair combinations.

3. Road Feeder Services / Air Cargo Trucking Links

3.1. Network Structure

Airline trucking networks first of all have a virtual character, describing connections that may be realized with forwarding partners, not necessarily as exclusive truck journeys. However, the market presence is multiplied. The visualized RFS network graph of American Airlines, as an example for a passenger airline, is depicted in Figure 5. Figure 6 illustrates how LH Cargo's road network covers the whole market of the contiguous U.S. and Canada.

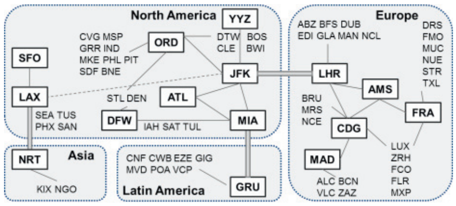

Fig. 5. Scheduled RFS network of American Airlines (Source: Own representation based on OAG, 2010)

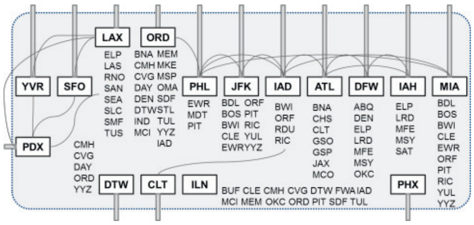

Fig. 6. Lufthansa Cargo's Scheduled RFS network for North America (Source: Own representation based on OAG, 2010)

3.2. Timetable analysis

A sample of RFS legs from 16 carriers, extracted from a 2010 July week's Official Airline Guide (OAG) timetable, was analyzed. The composition of the sample, average distances covered by continent, and the frequency distribution of duration in days are shown in Tables 3a/b. Most of the RFS (81.5%) were operated as same day or overnight deliveries.

Table 3a/b. Composition of RFS sample (a) and distribution of transport durations (b) (Source: Own computation, based on OAG, 2010)

IATA Region	Frequencies/week	Average GCD (km)
Europe	4,920	481
North America	3,777	829
Asia	781	670
Others	220	331
All	9,698	651

Duration	Count	proportion (per cent)
same day	524	22.4
over night	1,381	59.1
three days	277	11.9
four to six days	154	6.6
Total	2,336	100.0

The distribution over a 24 hour interval exhibits distinctive peaks am 9 AM local time for arrivals and 9 PM (or 8 to 11 PM in Europe) for departures (Figure 7a/b). With regard to the weekly profile, the relative number of schedules services slightly rises from Monday through Friday, with reduced or even no service during weekends (Figure 8a). A time-space plot (Figure 8b, *n*=2,336) displays a wide variety of speeds for equal distances. The average straight-line speed is moderate; 600 kilometer require more than 20 hours. The modeled journey times for access and egress trucking links may be cross-checked at the continent level by the empirically found ones.

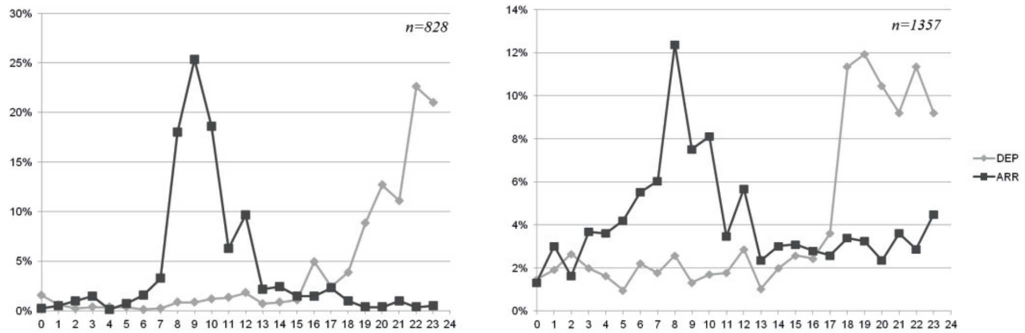

Fig. 7a/b. 24-hour distribution of RFS Services in North America (a), and Europe (b) (Source: Own representation based on OAG, 2010)

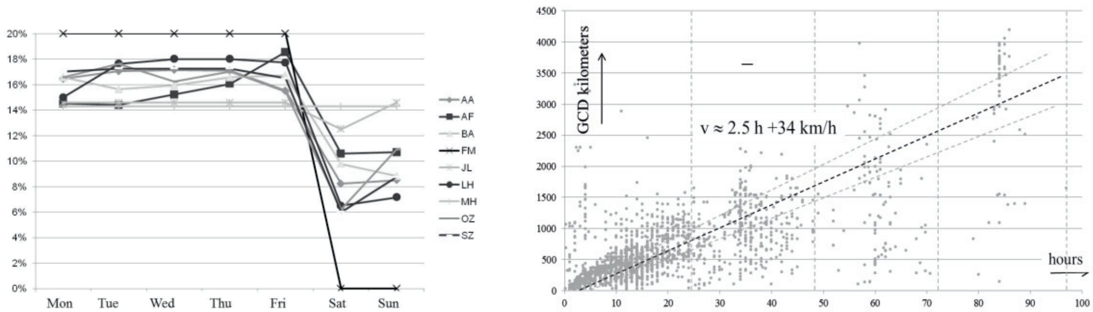

Fig. 8a/b. Weekly distribution of RFS departures (a), Time-distance diagram (b) (Source: Own representation based on OAG, 2010)

3.3. Road network assignment of RFS trucks

The assignment of virtual RFS connections as of July 2011 to the physical road links was conducted exemplary for the European continent, using the Federal DoT road model of Germany. Figure 9 gives insights into the geography of the air cargo hubs' hinterlands. The vast majority of the RFS connections centers around the compact, densely inhabited corridor of industry and services, stretching from the Midlands via the Rhine Valley to Northern Italy. There is an especially dense schedule towards and between the conurbations of London (LHR), Amsterdam (AMS) and Paris (CDG). Besides that, harboring hubs such as Frankfurt (FRA), Copenhagen (CPH), Milan (MXP), and Vienna (VIE) attract additional air cargo demand through surface transport.

With the help of the resulting RFS load pattern, Trans-European road links of relevance for the shipment of airfreight can be identified. Outcomes were compared with related results of the *WordNet* project (CEC, 2009).

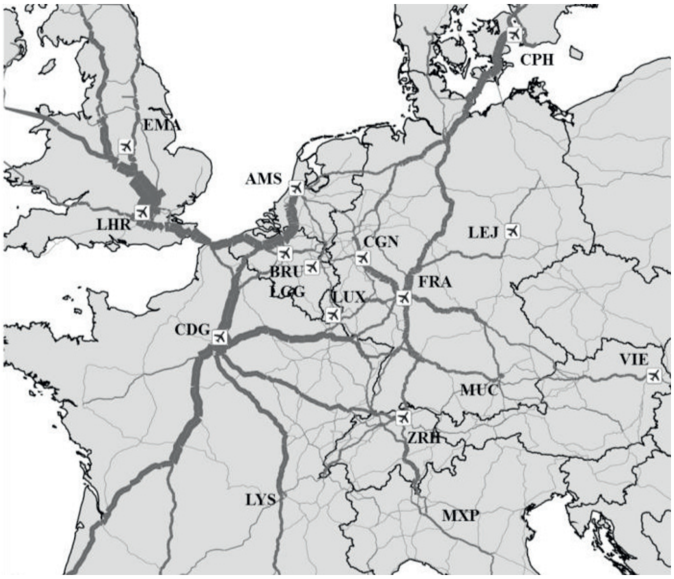

Fig. 9. Road Network Assignment of European RFS Services July 2011 in Frequencies per Week (Source: Own representation)

4. Integration in an air cargo modeling framework

The concepts of representing air cargo road transport links was built into our air cargo model under development. This model is aimed at an all-embracing description of air cargo quantity structures at a global scale. Its main task is to transfer a given or created "true O-D" air cargo flow matrix into itinerary level demand.

The model uses period timetables on a sample week basis, including all scheduled air cargo services; that is, belly cargo in connection with capacities of scheduled passenger flights, scheduled CAO flights with freighters, or scheduled trucking services. The two combinations, referred to as "CAO" (freighter + trucking) and "ALL" (freighter + belly cargo + trucking) in the following, describe distinct versions of time-space networks and the correspondingly segmented demand. This bipartition was made because hazardous or too bulky shipment may have to be excluded for passenger flights.

4.1. Origin and destination routing

The supply side model instance currently comprises 90 traffic cells linked to more than 1,100 airports by about 1,300 road connectors. Basically, for every O-D transport relation *i-j* there are three orthogonal dimensions of routing – geography in terms of the city pairs *p-q*, supplier networks *a* and departure day *d* of the represented week (Figure 10). The consideration of connectors from conceivable sets {*i-p*} and {*q-j*}, that is, the mapping of transports originating or terminating at traffic cells to/from the airports of consolidation and deconsolidation, directly affects the relevant choice dimension for forwarder trucking links. To assure the representation of all relevant zone-to-airport surface transport links, even hypothetical connectors were implemented. The hub airports listed in table 4 were linked to all traffic cell centroids within a 50-hour catchment diameter, provided that a surface road transport exists. Remaining connectors of non-hub airport to traffic cells besides the airport's traffic cell were introduced if relevant, and if the straight-line distance to the zone centroid did not exceed 300 km. These boundaries may be adjusted for time-critical commodity groups.

Table 4. Hub airports with road access/egress connectors across traffic cell boundaries (Source: Own representation)

Asia/Pacific	Middle East/Africa	Europe	North America	Latin America
KUL, SIN, BKK, PVG, HKG, DEL, NRT, ICN, KIX, PEK, SYD	AUH, DXB,NBO, CAI, JNB, ACC, DOH, SHJ	CDG, FRA, LHR, AMS, IST, SVO	ANC, EWR, CVG, HNL, LAX ORD, PDX, PHX, PHL, SLC,	MEX, GRU, VCP, SCL

In contrast to the previously described access/egress links, RFS services operate at the city pair level. They are carrier-exclusive, an integral part of the airlines' timetable, and will thus become part of the route-search on time-space graphs. Road feeder timetables of 32 scheduled sub-networks formed by about 50 airlines, including combined passenger/cargo airlines and five integrators, were implemented so far. Legs with code share were filtered out, splitting the planned freight between the respective capacitated links of the operating and marketing carriers. Each of the carrier sub-networks has two routing agents – for the "ALL" and "CAO" case. Every routing agents invokes a single source shortest-path algorithm to search optimal itineraries for all tuples $\{p(i), q(j), a, d\}$.

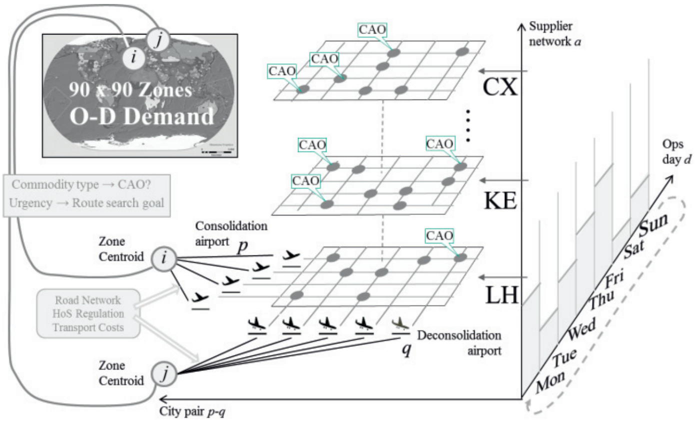

Fig. 10. Systematizing multi-dimensional route choice of O-D cargo flows (Source: Own representation)

4.2. Network demand assignment

The complex approach to air cargo routing is maintained by a multi-stepped spill-and-recapture demand assignment algorithm, aiming at a broad and realistic distribution of global air cargo flows while observing the weight limits, volumetric capacities, and further operational constraints. As reported in detail in the article of Heinitz and Meincke (2013), the three-dimensional choice set allows for exploring a substantial number of itineraries ascertainable. With regard to the residual time-space networks, a remaining conceptual problem is to deal with the unknown weight limit of RFS. The OAG database entries for RFS assume an exemplary value of 10 tons. Two model instances were calibrated for the sample week timetables of summer 2011 and winter 2011/12. Selected computational are given in Table 5 and 6.

Table 5. Airport Access and Egress, Road Transport Performance– Modeling Results for 2011 (Source: Own representation)

IATA Region	Tonnage [10^3 t/year]	Tpt. Performance [10^6 FTK/year]
EUR	15,132	4,207
NOA	27,664	11,896

Table 6. RFS tonnage, tpt. performance and utilization, by selected carriers – Demand assignment results 2011 (Source: Own representation)

Carrier	[10^3 t/year]	[10^6 FTK/year]	Avg. GCD [km]	Planned [10^6 FTK/year]	Avg. Utilization [%]
AA	168.6	84,693	502	185,096	46
BA	129.2	125,415	971	273,578	46
EK	293.2	192,093	655	635,174	30
IB	149.0	193,309	1,297	490,621	39
NH	84.6	47,016	556	84,101	56
SK	44.5	14,811	333	26,859	55

5. Summary and Discussion

Overland air freight transportation - an intermodal complement and alternative to air cargo flights - was characterized and modeled as part of an overall conceptual approach that supports the investigation of present and prospective airfreight quantity structures. The distinguishing features of this approach are the O-D scope in combination with the explicit use of period timetables of a sample week, not just weekly averages. The detailed consideration of O-D markets adds considerable complexity. The range of model outputs allows for a comparison with real-world data and existing discrete choice models at the airport level. Based on this, scenarios for policy recommendations towards a socially optimal division of labor road/air can be tested. Potential fields of model application comprise the estimation of the future RFS market sizes, economic and ecological performance indicators depending on airport curfew regulations, enhanced road access in developing countries, the dimensioning of new road-air terminals, and their airfreight security installations. Model improvements envisaged include road/air vs. air/air transfer cost differentials and generalized link cost functions for the itinerary search, the segmentation into commodity groups of different time/price sensitivity, pre-allocated block space by forwarders, a micro-foundation of itinerary choice, and high-speed cargo rail links as proposed in Ebeling (2008).

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